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Cooke

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(54) **INJECTION NOZZLE**

(75) Inventor: **Michael P. Cooke**, Gillingham (GB)

(73) Assignee: **Delphi Technologies Holding S.arl**, Troy, MI (US)

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(51) **Int. Cl.**
F02M 63/00 (2006.01)

(52) **U.S. Cl.** **239/533.2**; 239/102.2; 239/533.3; 239/533.12; 239/584

(58) **Field of Classification Search** 239/102.2, 239/533.4, 533.8, 533.9, 533.11, 533.12, 239/585.5, 900, 5, 87, 533.2, 533.7, 584, 239/585.1–585.4

See application file for complete search history.

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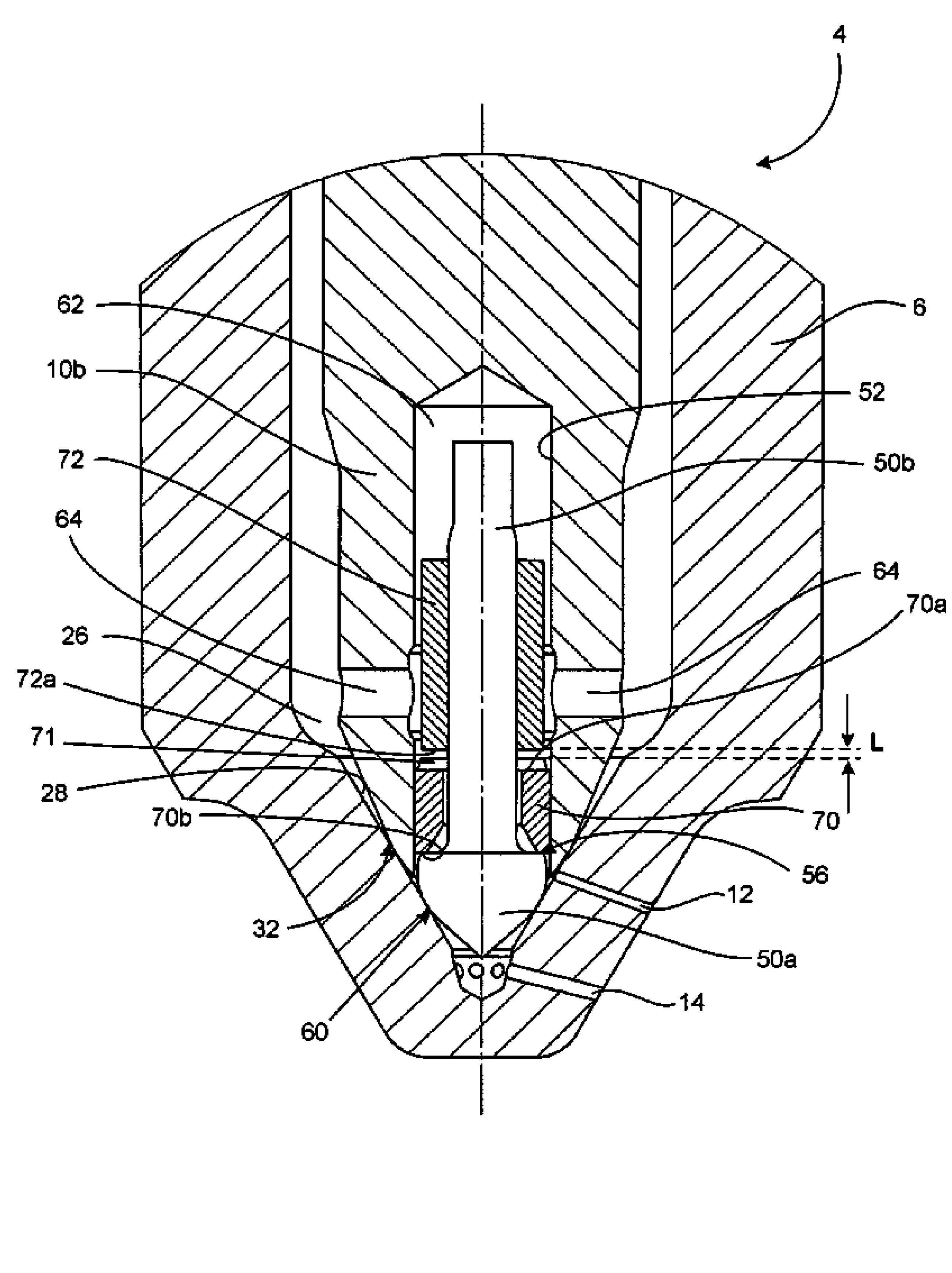
Primary Examiner—Jason J Boeckmann
(74) *Attorney, Agent, or Firm*—Thomas N. Twomey

(57) **ABSTRACT**

The invention relates to a fuel injection valve for internal combustion engines, comprising a valve body (**1**), with a drilling (**3**) embodied therein and defined at the combustion chamber end thereof by a conical valve seat (**18**) from which at least one injection opening (**20**) leads. A hollow valve needle (**8**) is arranged in the drilling (**3**) such as to be displaced longitudinally, comprising a valve sealing surface (**35**) at the end thereof facing the valve seat (**18**). A first sealing region (**31**; **34**) and a second sealing region (**32**; **46**; **48**) are embodied on the valve sealing surface (**35**), whereby, on contact of the hollow valve needle (**8**) on the valve seat (**18**), the first sealing region (**31**; **34**) provides a seal upstream of the at least one injection opening (**20**) and the second sealing region (**32**; **46**; **48**) downstream thereof.

21 Claims, 9 Drawing Sheets



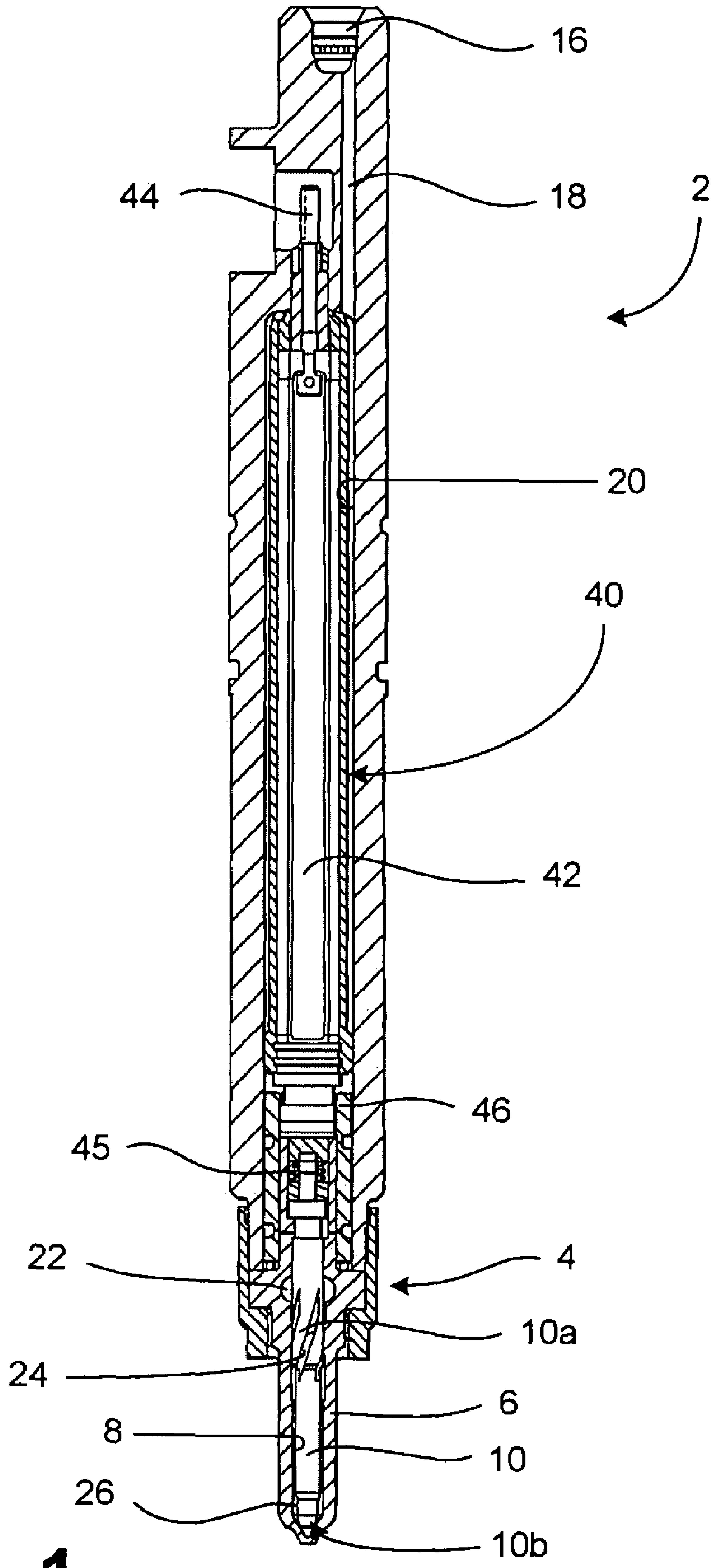


Fig. 1

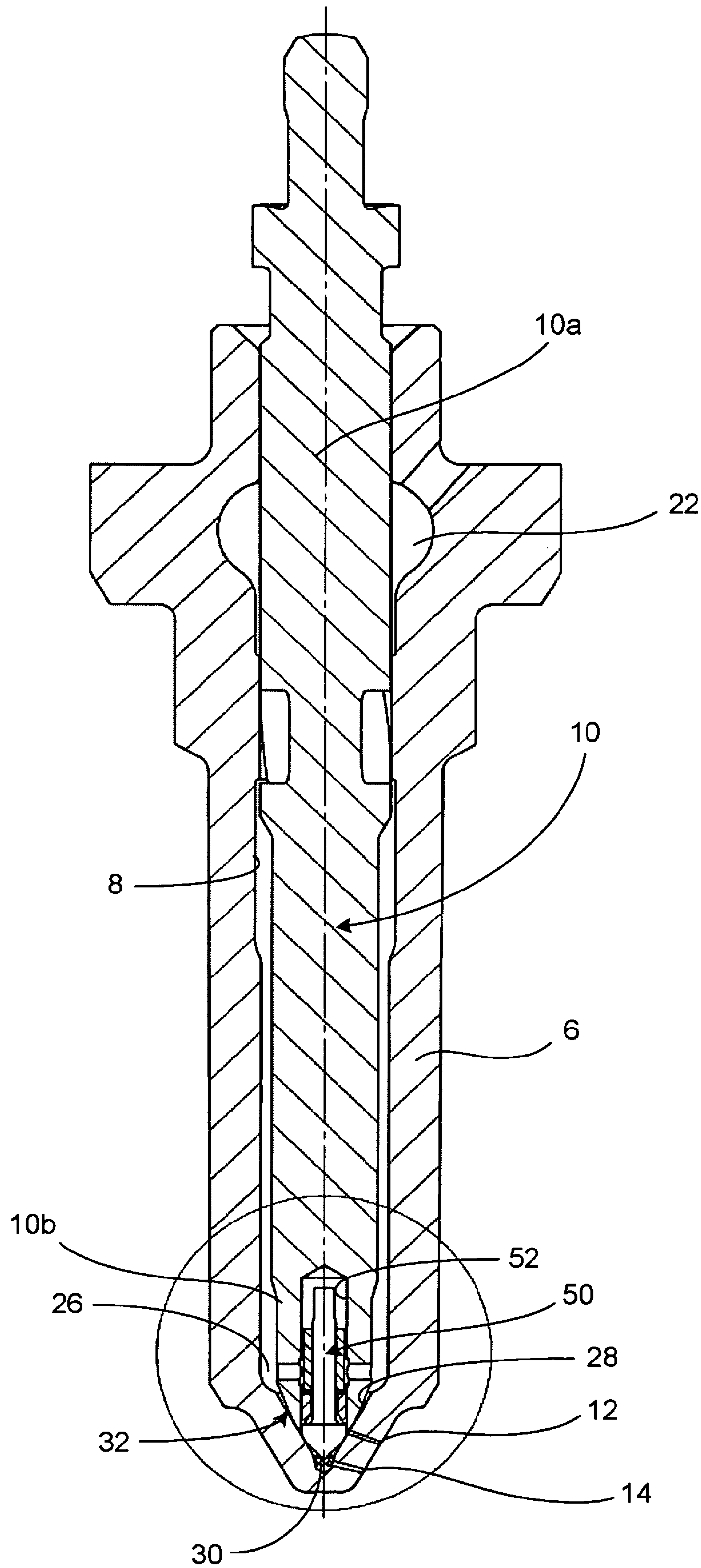


Fig. 2

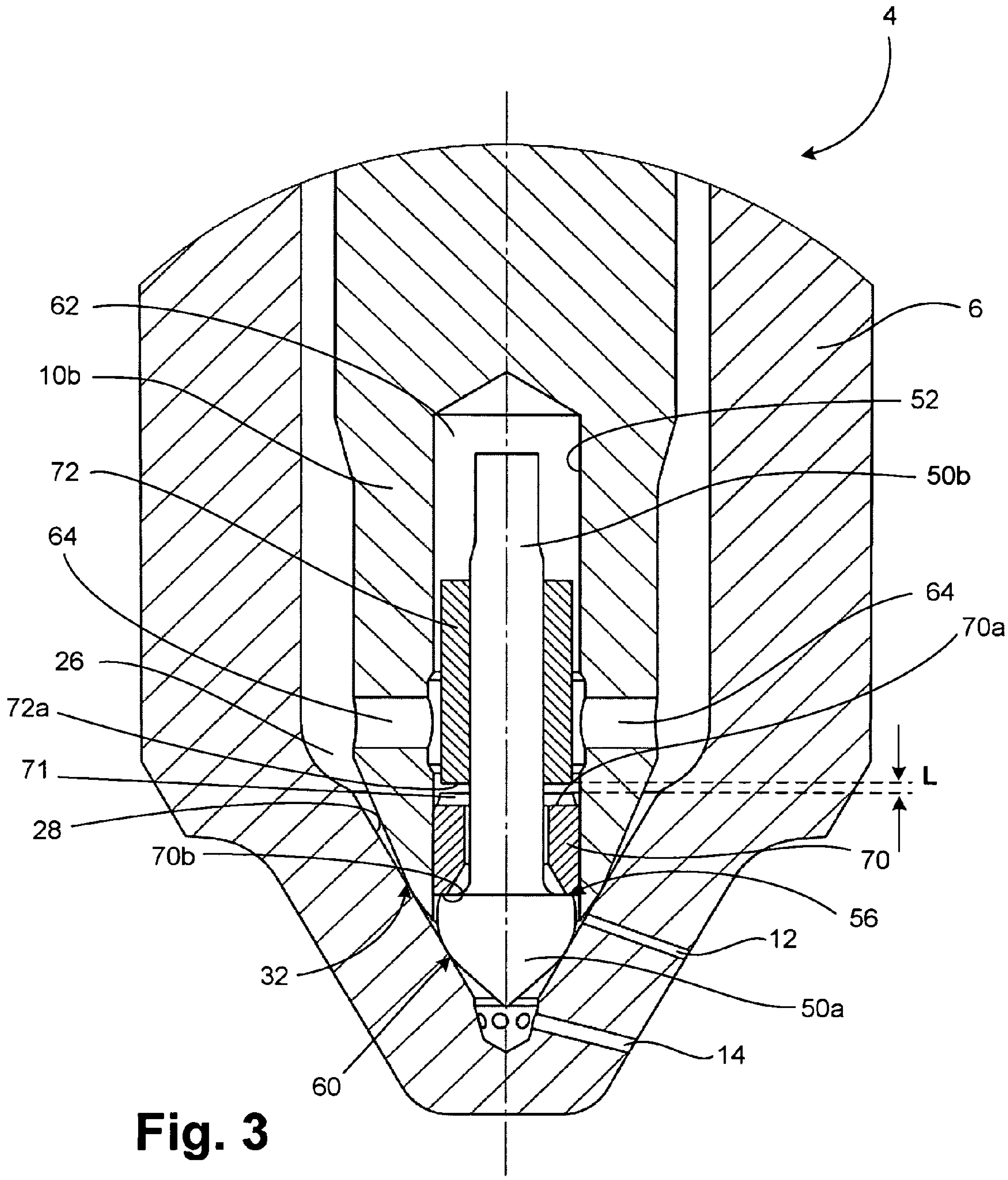


Fig. 3

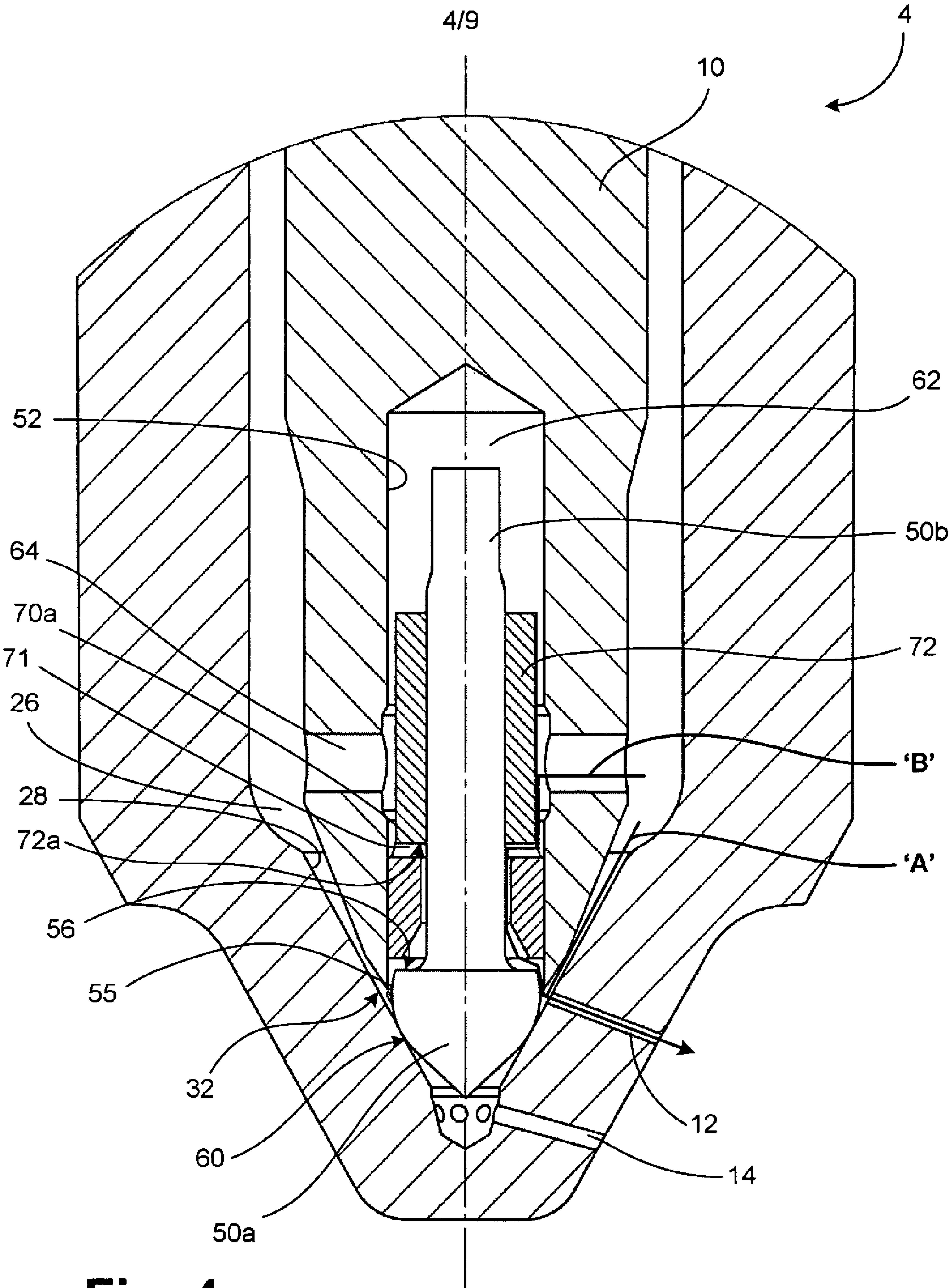


Fig. 4

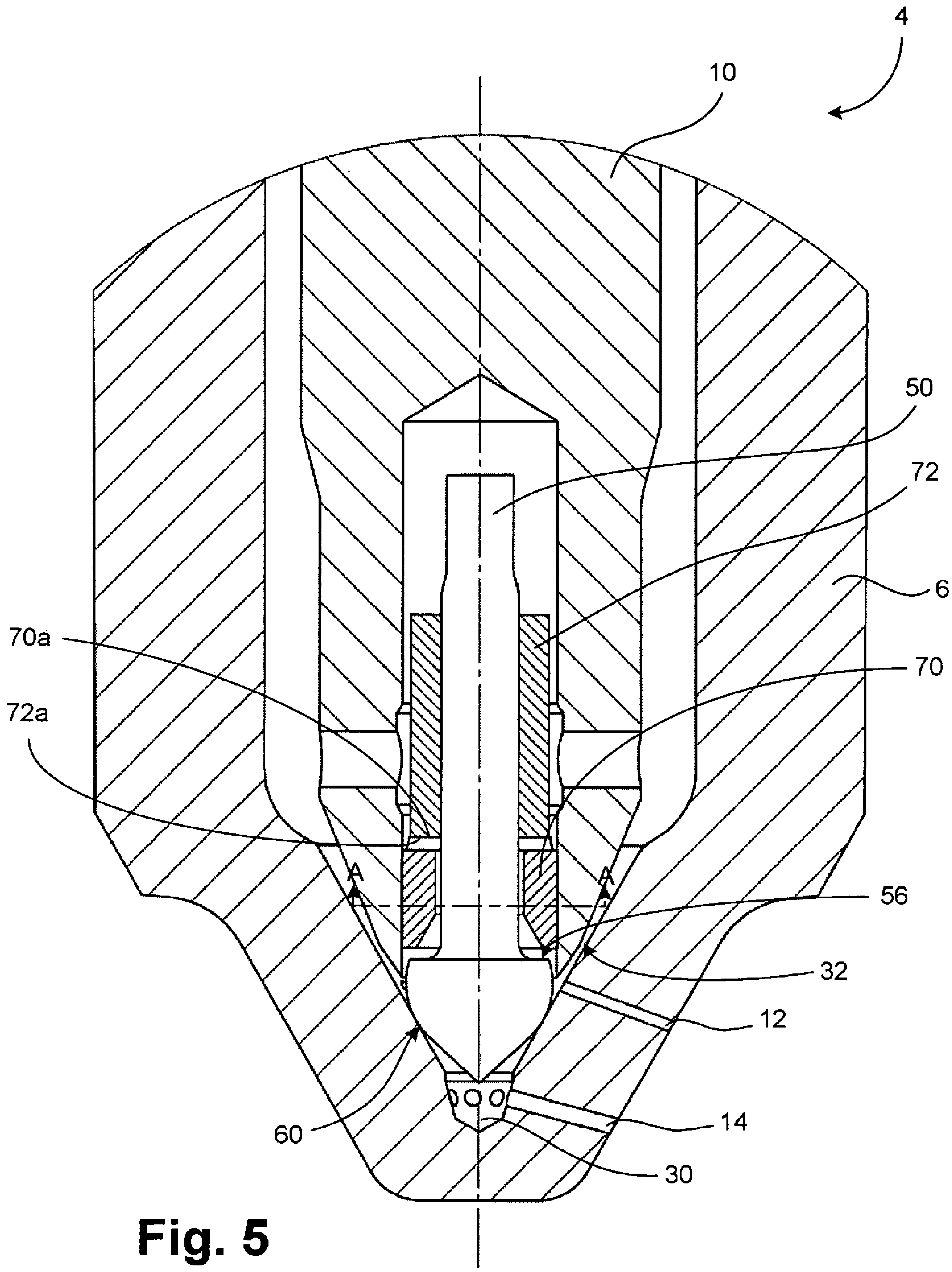


Fig. 5

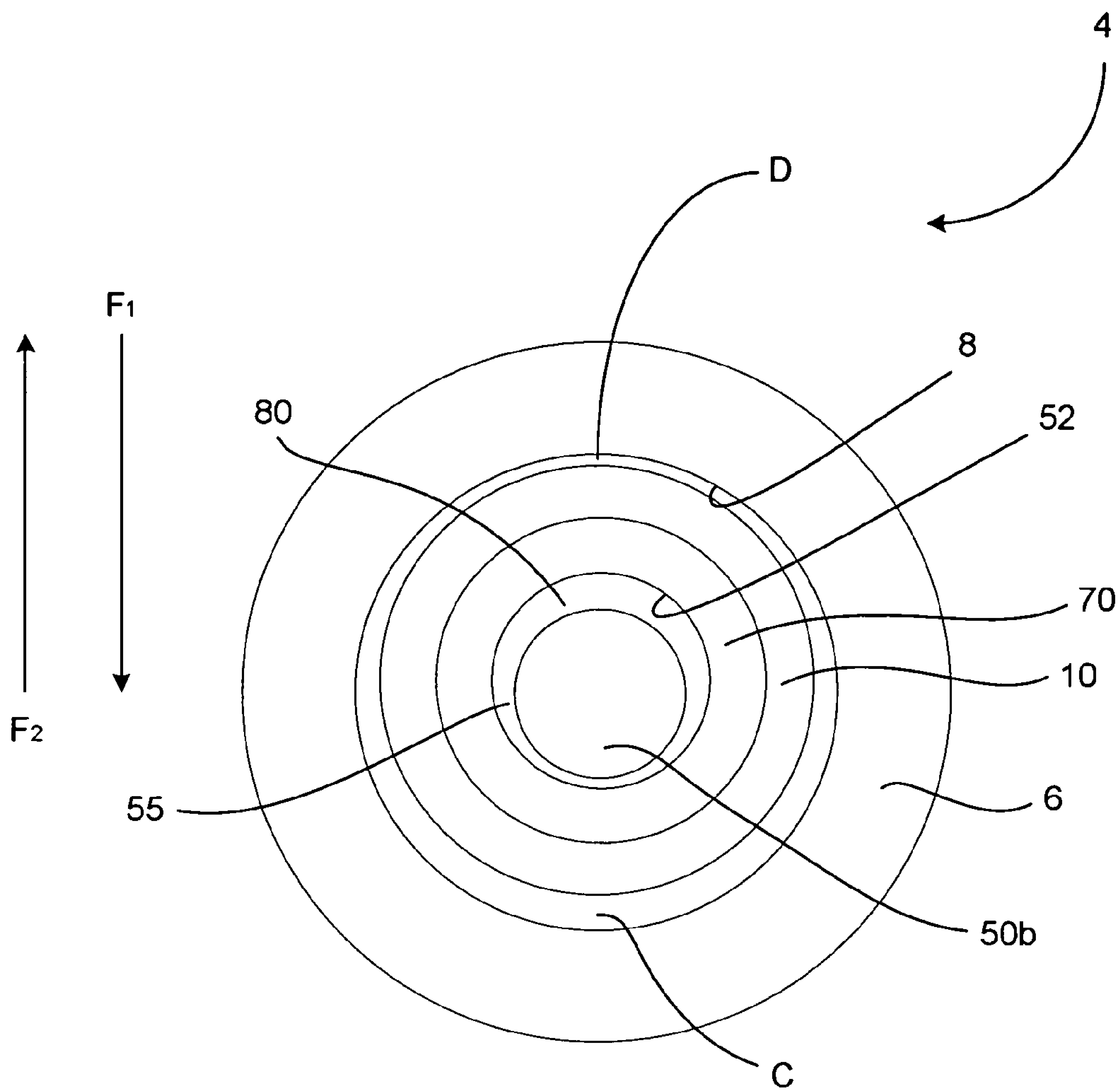


Fig. 6

A - A

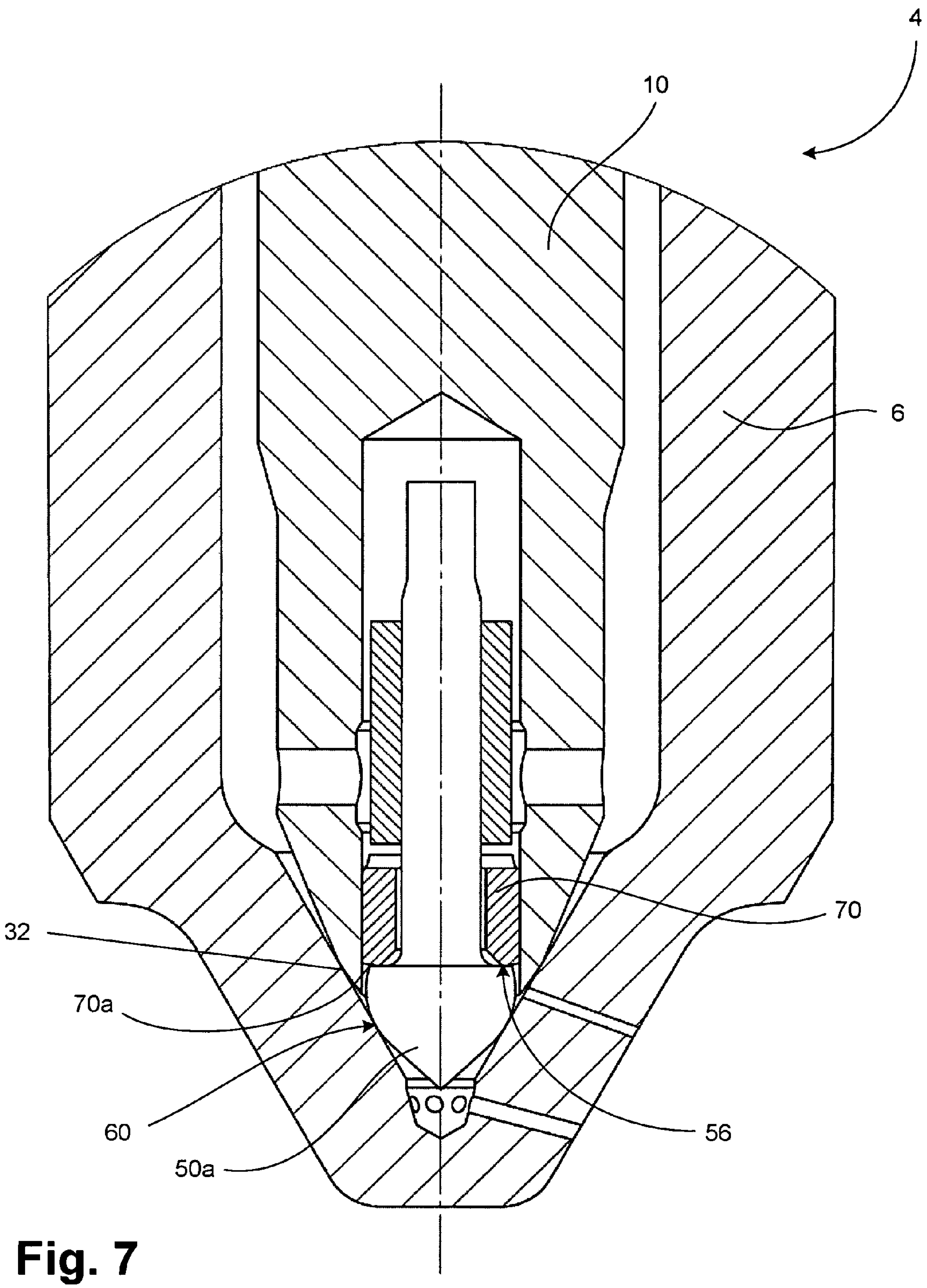


Fig. 7

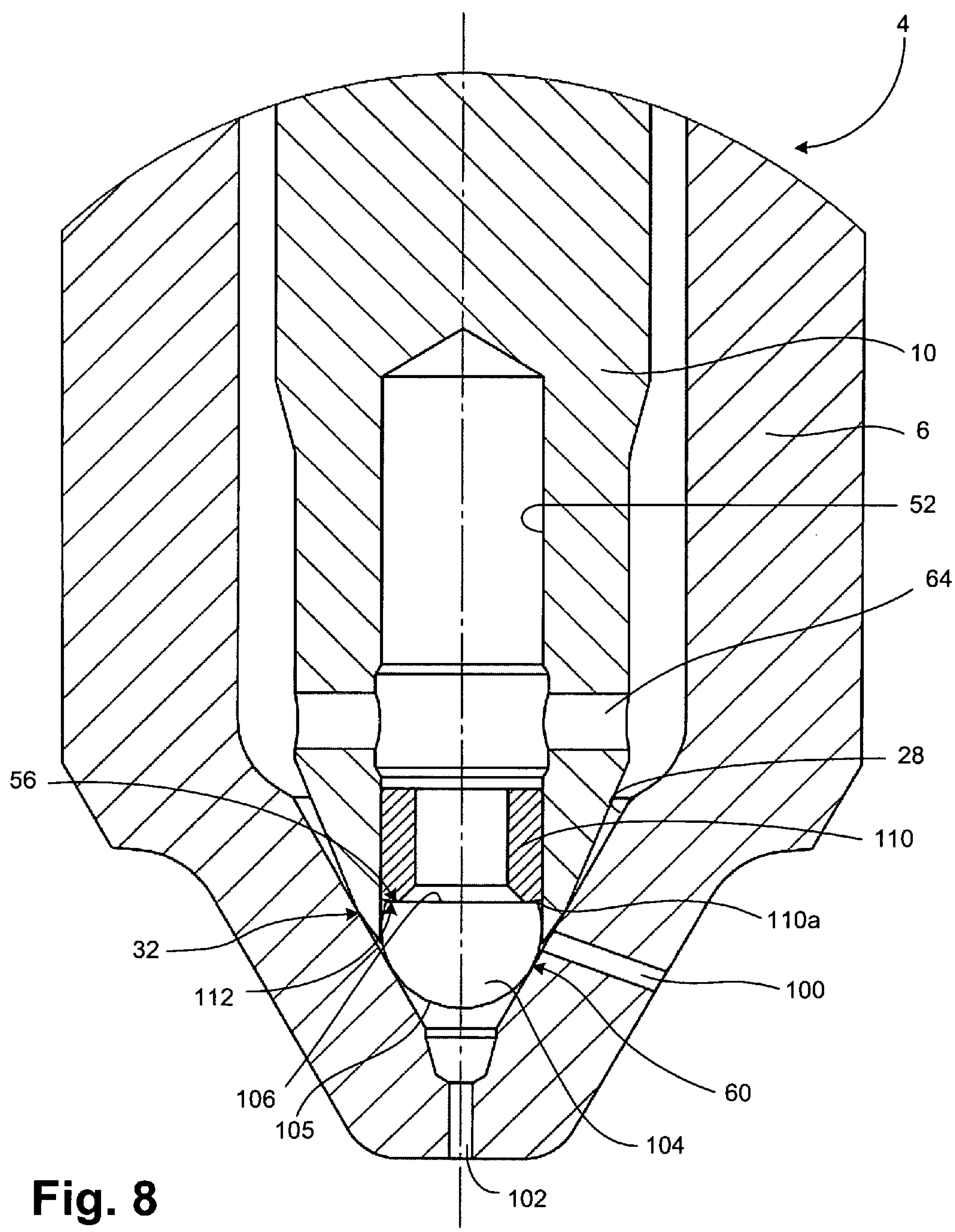


Fig. 8

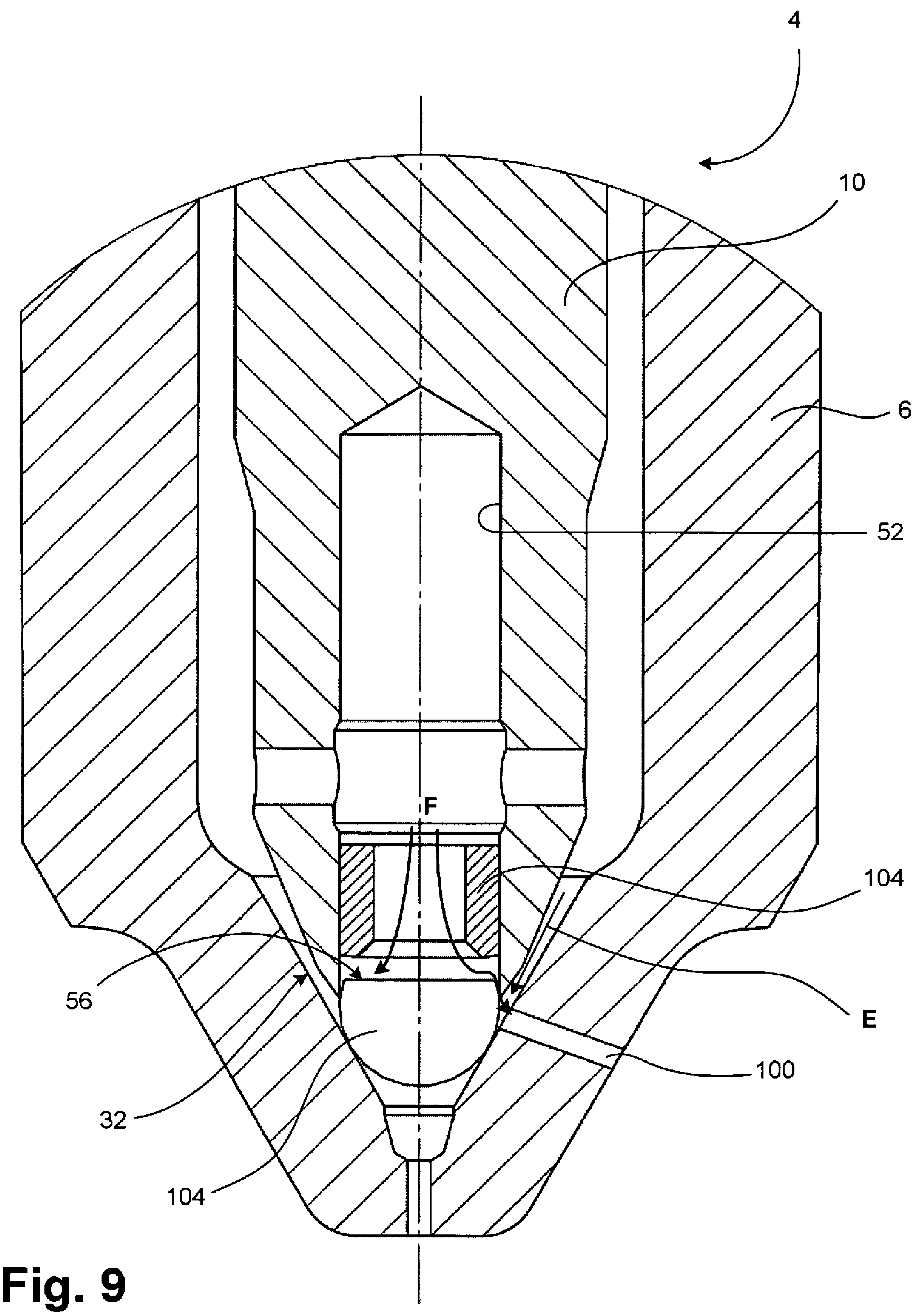


Fig. 9

INJECTION NOZZLE

TECHNICAL FIELD

The present invention relates to an injection nozzle for use in a fuel injector for an internal combustion engine. More particularly, although not exclusively, one aspect of the present invention relates to an injection nozzle for use in a compression ignition internal combustion engine in which at least one valve is operable to control the injection of fuel into a combustion space through one or more nozzle outlets.

BACKGROUND TO THE INVENTION

Due to increasingly stringent environmental regulations, a great deal of pressure is levied upon automotive manufacturers to reduce the level of vehicle exhaust emissions, for example, hydrocarbons, nitrogen oxides (NOx) and carbon monoxide. As is well known, an effective method of reducing exhaust emissions is to supply fuel to the combustion space at high injection pressures (around 2000 bar for example) and to adopt nozzle outlets of a small diameter in order to optimise the atomisation of fuel and so improve efficiency and reduce the levels of hydrocarbons in the exhaust gases. Although the above approach is effective at improving fuel efficiency and reducing harmful engine exhaust emissions, an associated drawback is that reducing nozzle outlet diameter conflicts against the requirement for high fuel injection flow rates at high engine loads and so can compromise vehicle performance.

So-called "variable orifice nozzles" (VONs) enable variation in the number of orifices (and therefore the total orifice area) used to inject fuel into the combustion space at different engine loads. Typically, such an injection nozzle has at least two sets of nozzle outlets with first and second valves being operable to control whether fuel injection occurs through only one of the sets of outlets or through both sets simultaneously. In a known injection nozzle of this type, as described in the Applicant's co-pending European patent application no. EP04250928, the fuel flow to a first (upper) set of nozzle outlets is controlled by an outer valve and the fuel flow to a second (lower) set of nozzle outlets is controlled by an inner valve. The inner valve is lifted by the outer valve only after the flow of fuel through the first set of nozzle outlets has reached a sufficient rate. An injection nozzle of this type enables selection of a small total nozzle outlet area in order to optimise engine emissions at relatively low engine loads. On the other hand, a large total nozzle outlet area may be selected so as to increase the total fuel flow at relatively high engine loads.

Although beneficial in many ways, such nozzles do have associated problems. For instance, if the valves do not lift with perfect concentricity, high side loads can be generated due to the hydraulic pressure being significantly lower on the side of the outer valve closest to the nozzle body. Under some conditions these side loads can be high enough to prevent the outer valve closing.

One aspect of the present invention relates to a variable orifice nozzle which aims to have the advantages of the above designs, but which serves to alleviate or overcome the aforementioned side load problem.

SUMMARY OF THE INVENTION

To this end, the invention resides in an injection nozzle for an internal combustion engine. The injection nozzle comprises: a nozzle body defining a seating surface and having a first nozzle outlet and an outer valve member received within the nozzle body and being engageable with an external seating defined by the seating surface so as to control fuel injection through the first nozzle outlet. The outer valve member is provided with a bore having an internal bore surface. An insert is received within the bore, defining an annular gap with the internal bore surface. The outer valve member is engageable with an internal seating defined by a surface of the insert to control fuel flow through the annular gap to the first nozzle outlet. The arrangement is such that the outer valve member is arranged to disengage with the external seating at the same time as it disengages with the internal seating such that the fuel which is to be ejected from the nozzle is always caused to flow simultaneously along: (a) a first path between the outer valve member and the external seating; and (b) a second path through the annular gap.

An injection nozzle having a combination of features as set out above has been found to provide particular benefits. For example, the outer valve member is provided with both an internal seating and an external seating, one defined being by the nozzle body and one being defined by the insert in the outer valve bore. By providing the insert to define the internal seating, there is no restriction on the seats being at different axial heights (as in the case where two external seats are provided), so that the internal and external seats can be provided at approximately the same, or similar, axial positions. This means that the vertical area of the valve member exposed to unequal side forces near the outlet is reduced. Furthermore, the external seating and the internal seating can be positioned along the axis of the nozzle body in approximate alignment, at least in circumstances in which the outer valve member is seated.

The insert may include a part-spherical head which spans the internal diameter of the bore to define the annular gap. Preferably, the internal seating is defined by a surface of the part-spherical head. The provision of the part-spherical head on the insert means that any misalignment at the internal seating for the valve member is accommodated by the head being able to move angularly about the centre of its sphere. As the internal seating can be located close to the centre of the sphere, any torque at the internal seating resisting the realignment is minimised.

In one embodiment, the injection nozzle includes a second nozzle outlet provided in the nozzle body, wherein the insert is an inner valve member which is slidable within the bore and engageable with the insert seating defined by the seating surface so as to control fuel injection through the second outlets.

Further, it is preferred for an annular member to be received within the bore so as to be engageable with the internal seating. It is envisaged that the annular member will be a separate component from the main body of the outer valve member. Alternatively, the outer valve member may be machined such that the annular member is formed integrally therewith.

The injection nozzle may further comprise a sleeve member that is coupled to the inner valve member, wherein the annular member is brought into engagement with the sleeve member when the outer valve member is moved axially through a distance that is greater than a predetermined distance so as to impart axial movement to the inner valve member also.

Preferably, the annular member and the sleeve member have opposed end faces which are spaced apart by the predetermined distance when the outer valve member and the inner valve member are seated against their respective seatings.

In one embodiment, an end face of the annular member that engages the internal seating is substantially flat. However, in some respects, it is beneficial for the end face of the annular member that engages the internal seating to be frusto-conical. A frusto-conical end face generates a distinct annular seating line against the flat upper face of the part-spherical head, which provides an improved seal that is more tolerant of flatness errors and less likely to trap dirt.

Further, it is preferred that inner valve member includes a valve stem, wherein the internal seating is defined by a shoulder between the part-spherical head and the valve stem.

In another embodiment of the invention, the insert does not take the form of a moveable valve member. Instead, the insert may remain engaged with the insert seating during all stages of nozzle operation.

Also in this embodiment, the outer valve member may include an annular member which is received within the bore of the outer valve member so as to be engageable with the internal seating.

Preferably, the nozzle body is provided with a vent passage through which fuel can escape in the event of fuel leakage past the insert seating.

In any embodiment of the invention, the injection nozzle may further comprise an arrangement for urging the insert against the insert seating. For instance, the arrangement for urging the insert against the insert seating may include at least one opening formed in the outer valve member which enables fuel to enter the bore, thereby to apply a hydraulic closing force to the insert. In addition, a spring may be provided to urge the insert against the insert seating.

The above described embodiments provide a fuel flow path past the external seating to the first outlet, and a supplementary flow path to the first outlet past the internal seating when the outer valve member is unseated. The supplementary flow path may include at least one channel provided on the insert.

In a second aspect, the invention resides in an injector for use in an internal combustion engine, wherein the injector includes an injection nozzle as described above and an actuator for operating the injection nozzle.

In order to optimise control over the volume of fuel that is delivered to the combustion chamber, it is preferred that the actuator is a piezoelectric actuator. However, another form of actuator could also be used, such as an electromagnetic actuator.

It will be appreciated that the preferred and/or optional features of the first aspect of the invention may be provided alone, or in appropriate combination, in the second aspect of the invention also.

BRIEF DESCRIPTION OF THE DRAWINGS

By way of example, the invention will now be described with reference to the accompanying drawings, in which:

FIG. **1** is a part-sectional view of a fuel injector in which an injection nozzle in accordance with the embodiments of the present invention may be incorporated;

FIG. **2** is a part-sectional view of the injection nozzle according to a first embodiment of the invention when in a non-injecting position;

FIG. **3** is an enlarged part-sectional view of the injection nozzle in FIG. **2**;

FIG. **4** is a part-sectional view of the injection nozzle in FIGS. **2** and **3** when in a first injecting position;

FIG. **5** is a part-sectional view of the injection nozzle in FIG. **2** when in a second injecting position;

FIG. **6** is a sectional view of the injection nozzle in FIG. **5** along the line A-A during circumstances in which the outer valve needle lifts eccentrically;

FIG. **7** is an enlarged part-sectional view of an injection nozzle according to a second embodiment of the present invention when in a non-injecting position;

FIG. **8** is an enlarged part-sectional view of an injection nozzle according to a third embodiment of the present invention when in a non-injecting position; and

FIG. **9** is a part-sectional view of the injection nozzle in FIG. **8** when in a first injecting position.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following description, the terms "upper" and "lower" are used having regard to the orientation of the injection nozzles as shown in the drawings. Likewise, the terms "upstream" and "downstream" are used with respect to the direction of fuel flow through the nozzle from a fuel inlet line to fuel outlets.

FIG. **1** shows a piezoelectric fuel injector, referred to generally as **2**, within which an injection nozzle **4** in accordance with the invention is incorporated. FIG. **2** shows the injection nozzle in greater detail. The fuel injector **2** is of the type described in Applicant's U.S. Pat. No. 6,776,354.

The injection nozzle **4** includes a nozzle body **6** provided with an axial bore **8** within which an outer valve member **10** in the form of a needle is slidably received. The nozzle body **6** also includes respective first and second sets of nozzle outlets **12**, **14** (not shown in FIG. **1**) through which fuel can be injected into a combustion chamber, in use.

Fuel is supplied to the injector **2** via an injector inlet **16** from, for example, a common rail or other appropriate source of pressurised fuel, which is also arranged to supply fuel to one or more other injectors. Pressurised fuel is communicated from the inlet **16**, through an inlet passage **18** and an accumulator volume **20**, to an annular chamber **22** defined within the bore **8** between the nozzle body **6** and an upper end region **10*a*** of the outer valve needle **10**. The upper end region **10*a*** has a diameter substantially equal to that of the nozzle body bore **8** such that, in use, co-operation between these parts serves to assist in guiding movement of the outer valve needle **10** as it reciprocates within the bore **8**. Spiral flutes **24** machined into the upper region **10*a*** provide a flow path for fuel to be communicated from the annular chamber **22**, through the bore **8** and into a nozzle delivery chamber **26** located towards the tip of the outer valve needle **10**. The delivery chamber **26** is defined between the outer surface of the outer valve needle **10** and the nozzle body bore **8** in a region upstream of the outlets **12**, **14**.

Towards its blind end, the nozzle body bore **8** defines a conical seating surface **28** that terminates in a sac volume **30**. The seating surface **28** defines an external seat **32** with which a tip region **10*b*** of the outer valve needle **10** is engageable to control fuel injection through the first set of nozzle outlets **12**.

As shown in FIG. **1**, movement of the outer valve needle **10** is controlled by means of a piezoelectric actuator **40**. The piezoelectric actuator **40** comprises a stack **42** of piezoelectric elements, arranged within the accumulator volume **20**, and an electrical connector **44** which enables a voltage to be applied across the stack **42**. In use, the accumulator volume **20** forms a part of a supply passage to the injection nozzle **4** and, as it is filled with high pressure fuel, applies a hydrostatic loading to the stack **42** which increases the operational efficiency of the stack **42**. The piezoelectric actuator **40** is coupled to the outer valve needle **10** via a hydraulic amplifier arrangement **46** and movement of the outer valve needle **10** is controlled by varying the voltage applied to the stack **42** in order to cause the stack **42** to extend and contract. When the voltage across the stack **42** is reduced, the stack **42** contracts so as to reduce its length and therefore a retracting force is applied to the outer valve needle **10**. Conversely, when the voltage is increased, the length of the stack **42** increases which applies a force urging the outer valve needle **10** into engagement with the seating surface **28**.

The outer valve needle **10** is biased towards the external seat **32** by means of a resilient member in the form of a closing spring **45** (shown in FIG. **1** only), and is operable to move away from the external seat **32**, against the force provided by the closing spring **45**, by means of the actuator.

It should be mentioned at this point that although in FIG. **2** a single outlet is shown in each set of outlets **12**, **14**, typically each set **12**, **14** will include a plurality of outlets. Therefore, for the purposes of this specification, reference to an 'outlet' should be taken to mean one or more outlets.

The injection nozzle **4** also includes an insert member **50** in the form of an inner valve needle which is slidably mounted within a blind axial bore **52** provided in the tip region **10***b* of the outer valve needle **10**. The lower end of the nozzle is shown more clearly in FIG. **3**.

In FIG. **3**, it can be seen that the inner valve needle **50** is shaped to include a part-spherical head **50***a* that tapers to a generally conical pointed tip. An upper stem region **50***b* extends upwardly from the part-spherical head **50***a* and is of generally uniform cross-section along its length having a diameter less than that of the head **50***a*.

At its widest point, where the part-spherical head **50***a* meets the stem **50***b*, the head **50***a* defines an upper surface that is received within the opening of the inner bore **52** and spans virtually the entire internal diameter thereof. However, the diameter of the part-spherical head **50***a* is slightly less than that of the outer valve bore **52** such that an annular gap **55** is defined between the periphery of the head **50***a* and the inward facing surface of the bore **52**.

The upper surface of the part-spherical head **50***a* is substantially flat and defines a shoulder which provides an internal seating **56** for the outer valve needle **10**. The outer valve needle **10** therefore has two seats i.e. the external seating **32** and the internal seating **56**.

In the non-injecting position illustrated in FIGS. **2** and **3**, the inner valve needle **50** is seated on an insert seating **60**, referred to as the inner valve seating, which is defined by a region of the seating surface **28** at a position below the first outlets **12**. Engagement between the part-spherical head **50***a* and the inner valve seating **60** thus controls fuel flow to the second outlets **14**, whilst engagement between the outer valve needle **10** and the internal and external seats **56**, **32** controls fuel flow to the first outlets **12**.

The upper end of the stem region **50***b* is accommodated in a chamber **62** defined by the blind end of the outer valve bore **52**. The chamber **62** is in communication with the nozzle body bore **8** via radial passages **64**, in the form of cross drillings, provided in the outer valve needle **10** so that pressurised fuel within the nozzle body **8** is able to flow into the outer valve bore **52** and the chamber **62**. Fuel pressure within the chamber **62** therefore acts on the inner valve needle **50** and so provides an arrangement for biasing the inner valve needle **50** against the inner valve seating **60**.

As has been mentioned, movement of the inner valve needle **50** towards and away from the inner valve seating **60** controls fuel injection through the second set of outlets **14**. However, unlike the outer valve needle **10**, the inner valve needle **50** is not actuated directly by the piezoelectric stack **42**. Instead, and as will be described in greater detail later, once the outer valve needle **10** has moved upwards (i.e. away from the external seating **32**) beyond a pre-determined distance, it conveys movement to the inner valve needle **50** causing it to move upwards also away from the inner valve seating **60**.

To this end, the outer valve needle **10** further comprises an annular member or ring **70** which is received within the outer valve bore **52**. The ring **70** is a separate and distinct part and is coupled to the outer valve needle **10** through frictional contact between the outer surface of the ring **70** and the internal surface of the outer valve bore **52**. That is to say, the ring **70** is an interference fit with the outer valve bore **52**. Together, the outer valve needle **10** and the ring **70** form a moveable valve arrangement. The ring **70** includes a first, upper end face **70***a* and a second, lower end face **70***b*.

In the closed position, the lower end face **70***b* of the ring **70** engages the internal seating **56** defined by the upper face of the part-spherical head **50***a* such that the inner valve needle **50** is held against the inner valve seating **60** by virtue of the ring **70** acting in combination with high pressure fuel within the chamber **62**. This is the position shown in FIG. **3**.

The internal diameter of the ring **70** is greater than the outer diameter of the inner valve stem **50***b*, such that the stem **50***b* passes through the ring **70** and defines a clearance fit therewith such that fuel may flow past the clearance between the inner facing surface of the ring **70** and the outer facing surface of the stem region **50***b*. The upper face **70***a* of the ring **70** defines fuel channels **71** in the form of slots or grooves to allow fuel to pass into the centre of the ring **70**, as will be described later.

In order for movement to be conveyed from the outer valve needle **10** to the inner valve needle **50**, the stem region **50***b* carries a substantially tubular member **72** in the form of a sleeve, which is a separate and distinct part from the inner valve needle **50**. The sleeve **72** has an external diameter that is less than the internal diameter of the outer valve bore **52**, such that the inner valve needle **50** is free to slide within the bore **52**. Further, the sleeve **72** has an internal diameter that is substantially equal to the outer diameter of the stem region **50***b* and, therefore, the sleeve **72** is an interference fit with the stem **50***b* and so is coupled to the stem **50***b* through frictional contact. A lower end face **72***a* of the sleeve **72** opposes the upper end face **70***a* of the ring **70**, the purpose of which will now be described in further detail.

When both the outer valve needle **10** and the inner valve needle **50** are seated, the lower end face **72***a* of the sleeve **72** and the upper end face **70***a* of the ring **70** are separated by a distance 'L' that is predetermined at manufacture. The distance 'L' determines the amount by which it is necessary for the outer valve needle **10** to lift away from its internal and external seatings **56**, **32** before engaging the sleeve **72** to convey movement to the inner valve needle **50**. It should be appreciated that the lower end face **72***a* of the sleeve **72** and the upper end face **70***a* of the ring **70** are at maximum separation (i.e. predetermined distance 'L') when both the inner valve needle **50** and the outer valve needle **10** are seated, as shown in FIG. **3**.

In use, fuel under high pressure is delivered from the common rail to the nozzle body bore **8** (and thus to the delivery chamber **26**) via the inlet **16**, the inlet passage **18** and the stack volume **20**, as shown in FIG. **1**. Initially, the piezoelectric actuator **40** is energised to a relatively high energisation level so that the stack **42** is in an extended state. In such circumstances, the outer valve needle **10** is held against its internal and external seatings **56**, **32** due to the biasing force of the closing spring **45**. The inner valve needle **50** is held against the inner valve seating **60** due to the pressure of the fuel within the chamber **62** and also by the ring **70** abutting the internal seating **56**.

Referring to FIG. **4**, in order to inject fuel through the first (upper) outlets **12** only, the stack is de-energised to a first, intermediate energisation level causing it to contract, resulting in a lifting force being transmitted to the outer valve needle **10**. The outer valve needle **10** is thus urged to move away from its internal and external seatings **56**, **32** to open a fuel flow path 'A' past the external seating **32** and, thus, through the first outlets **12**. It will be appreciated that the flow path 'A' to the outlets **12** which is opened as the outer valve needle **10** lifts from the external seating **32** is an annular flow path around the outer valve needle **10**, although in the section shown it is denoted by a single arrow.

In addition to the first fuel flow path 'A', a second fuel flow path 'B' is created as the lower surface **70***b* of the ring **70** disengages the internal seating **56**. Fuel flows along flow path 'B' from the delivery chamber **26**, through the radial drillings **64** and through the channels **71** provided in the upper face **70***a* of the ring **70** into the annular gap defined between the ring **70** and the stem region **50***b*. Since the ring **70** is disengaged from the internal seating **56**, fuel flows through the annular gap past the seating **56**, through the annular gap **55** between the opening of the outer valve bore **52** and to the first outlets **12**.

During this initial de-energisation of the stack **42**, the outer valve needle **10** is caused to move through a distance less than or equal to the distance 'L' (identified on FIG. **3**). The ring **70** is carried with the outer valve needle **10** so that the upper end face **70***a* of the ring **70** approaches the opposing lower end face **72***a* of the sleeve **72**. In FIG. **4**, the ring **70** is moved exactly through the distance 'L' so that it just makes contact with the sleeve **72**. Provided the distance through which the outer valve needle **10** moves is no greater than the pre-determined distance 'L', movement of the inner valve needle **50** remains decoupled from the outer valve needle **10**, thus the inner valve needle **50** will remain firmly seated against the inner valve seating **60** under the influence of pressurised fuel within the chamber **62**. Fuel is therefore unable to flow past the seated part-spherical head **50***a* of the inner valve needle **50** to the second outlets **14**.

The above described condition represents fuel injection optimised for relatively low power applications since a relatively small volume of fuel is injected through the first set of relatively small outlets **12** only.

If, at this point, it is necessary to terminate injection through the first outlets **12**, the stack **42** is re-energised to its initial energisation level causing the stack **42** to extend. As a result, the outer valve needle **10** is caused to re-engage both with the external seating **32**, defined by the conical seating surface **28**, and the internal seating **56**, defined by the part-spherical head **50***a*, under the influence of the biasing force of the closing spring **45** (shown in FIG. **1**).

FIG. **5** shows the injection nozzle during a subsequent, or alternative, stage of injector operation in which the stack **42** may be de-energised further to a second energisation level causing the stack length to be reduced further. As a result, the outer valve needle **10** is urged away from the internal and external seatings **56**, **32** by a further amount, which is greater than the predetermined distance 'L'. In such circumstances, the upper end face **70***a* of the ring **70** is caused to engage the lower end face **72***a* of the sleeve **72**, thereby causing movement of the outer valve needle **10** to be conveyed or coupled to the inner valve needle **50**. As a result, the inner valve needle **50** is caused to lift from the inner valve seating **60**.

As the inner valve needle **50** lifts away from the inner valve seating **60**, fuel within the delivery chamber **26** is able to flow past the internal and external seatings **56**, **32** to the first outlets **12**, but also past the inner valve seating **60** to the second (i.e. lower) outlets **14** and into the combustion chamber via the sac volume **30**. The flow through the second outlets **14** supplements the fuel flow through the first outlets **12** to provide a higher fuel injection rate suitable for higher engine power modes.

Termination of injection occurs if the stack **42** is energised once again to the higher energisation level, as described previously. Alternatively, the energised level may be increased slightly to the first level so that only the outer valve needle **10** is lifted and the inner valve needle **50** returns to the inner valve seating **60** so as to close the flow path to the second outlets **14**.

A particular benefit of the nozzle described previously is that the second flow path 'B' improves the flow efficiency of the injection nozzle **4** since there is a greater flow area for fuel for a given level of lift of the outer valve needle **10** compared to conventional VONs. In addition, the second flow path 'B' serves to reduce the pressure drop between positions upstream and downstream of the seats, **32**, **56**, **60** such that lateral side loads acting on the outer valve needle **10** are also reduced.

Furthermore, the above described arrangement has the effect of substantially balancing the side loads on the outer valve needle **10**. By way of explanation, FIG. **6** depicts a scenario in which the outer valve needle **10** has lifted away from the external seating **32** in an eccentric manner such that the clearance between the nozzle body bore **8** and the outer valve needle **10** at a first region 'C' is greater than a diametrically opposite region 'D'. It will be appreciated that the scale of the components and the clearances in FIG. **6** are exaggerated for the sake of clarity. Fuel flowing through the regions C and D therefore generate a side load in the direction of F**1**. However, since the part-spherical head **50***a* remains seated during relatively low needle lifts, the fuel flowing through the annular gap **80** (second fuel flow path 'B') between the stem region **50***b* and the outer valve bore **52** generates a side load in the direction of F**2** which opposes F**1**, and thus provides a balancing force. Therefore, the net side force acting on the outer valve needle **10** is substantially educed which reduces the tendency of the outer valve needle **10** to lift eccentrically.

A further benefit is achieved as the outer valve needle **10** seats against a component (the inner valve needle **50**) which has a part-spherical surface in engagement with the inner valve seating **60**. The part-spherical nature of the inner valve needle **50** allows it to rotate, or tilt, about the centre of its sphere to correct any misalignment of the internal seating **56** on its upper face. As the centre of the part-spherical head **50***a* is paced only a short distance from the internal seating **56** (i.e. a 'flat top' of the part-spherical head **50***a*), any torque on the inner valve needle **50** arising from friction at the seating **56**, which would otherwise resist the realignment, is minimal. As the internal seating **56** is defined by the upper surface of the part-spherical head **50***a*, this also means that the external seating **32** and the internal seating **56** can be approximately aligned along the longitudinal axis of the injection nozzle **4** when the outer valve needle **10** is seated, and only axially spaced by a relatively small amount (at most, by the predetermined lift distance L), when the outer valve needle **10** is lifted.

FIG. **7** shows a second embodiment of the invention, whereby instead of the lower face **70***a* of the ring **70** being flat, it is inclined at an angle to the horizontal (i.e. the lower face **70***a* is frusto-conical) in order to generate a distinct annular seating line **56** against the flat upper face of the part-spherical head **50***a*. Concentrating the seating **56** to a distinct annular line, rather than a face to face contact, is likely to give an improved seal which is more tolerant of flatness errors and less likely to trap dirt. It will be appreciated that it is also possible for the part-spherical head **50***a* to be manufactured with an inclined surface and the lower surface **70***a* of the ring **70** to be flat. However, this variant may be more challenging to manufacture since a frusto-conical surface would be more susceptible to concentricity errors.

At higher lifts, as the outer valve needle **10** is lifted further away from its internal and external seatings **56**, **32**, the effective location of the internal seat restriction will move towards the periphery of the outer valve bore **52** as the clearance between the part-spherical head **50***a* and the outer valve bore **52** becomes more restrictive than that at the internal seating **56**. That is to say, as the outer valve needle **10** is lifted higher the fuel flow is most restricted through the channel formed between the peripheral surface of the part-spherical head **50***a* and the inner surface of the outer valve bore **52**, as this channel becomes smaller relative to the spacing between the lower end face **70***a* of the ring **70** and the internal seating **56**.

Operation of the injection nozzle **4** in FIG. **7** would be implemented in a similar manner as for FIGS. **2** to **5**.

FIGS. **8** and **9** illustrate a third embodiment of the present invention. This embodiment is broadly similar to the above-described embodiments and like parts will be numbered accordingly and not described again here.

The third embodiment differs in that the nozzle body **4** is provided with only a single set of outlets **100** to the combustion chamber, but is however provided with an additional axially extending outlet or vent **102**, the function of which will be described later. A further modification is that the inner valve needle **50** is replaced with a substantially immovable part-spherical insert **104** having a part-spherical external surface **105** and a flat, upper surface **106**. The part-spherical surface **105** seats on the insert seating **60** and is received within the lowermost end opening of the outer valve bore **52**.

In this embodiment, the bore **52** in the outer valve needle **10** includes a ring **110** having a frusto-conical lower face **110***a* similar to that shown in FIG. **7**, although a ring **110** having a flat lower face could equally be used. The frusto-conical lower surface **110***a* thus defines an internal annular seating line **112** for the outer valve needle **10**. When the nozzle **4** is in the non-injecting position, the ring **110** seats against the internal seating **56** defined by the insert **104**.

The diameter of the outer periphery of the insert **104** is less than the diameter of the outer valve bore **52** such that a restricted annular flow path is defined between the periphery of the insert **104** and the inner surface of the outer valve bore **52**. The dimension of the gap is selected as a compromise between providing sufficient centring force to the outer valve needle **10** and providing sufficient fuel flow through the gap.

In the event that the ring **110** is slightly misaligned in the outer valve bore **52**, the insert **104** can adjust its seating angle on the insert seating **60** by rotating, or tilting, about the centre of its sphere, so that its flat upper face **106** can adopt the angle of the ring **110** and, hence, account for the misalignment. The set of nozzle outlets **100** is therefore sealed effectively from high pressure fuel at both the external and internal seatings **32**, **56** of the outer valve needle **10**.

High pressure fuel enters the outer valve bore **52** via the radial drillings **64** and, together with the force of the spring **45** (not shown in FIG. **8**), which is transmitted to the part-spherical insert **104** via the ring **110**, serves to hold the insert **104** in place against the insert seating **60**. The axial outlet **102** in the nozzle body **6** provides a vent underneath the insert **104** to ensure that any fuel leaking past the insert seating **60** into the tip of the nozzle body **6** simply vents into the combustion chamber. In this way, the insert **104** is prevented from lifting from the insert seating **60** because of fuel trapped beneath it.

Referring to FIG. **9**, when it is desired to inject fuel through the outlets **100**, the outer valve needle **10** is retracted by means of the piezoelectric stack **42** (not identified in FIG. **9**) causing the ring **104** to disengage from the internal seating **56**. In such circumstances, a first annular flow path ‘E’ opens up past the external seating **32** and a second annular flow path ‘F’ opens up past the internal seating **56** so that high pressure fuel can flow out through the outlets **100** into the combustion chamber.

As the part-spherical insert **104** is effectively rooted to the inner seating **60** by virtue of the high pressure fuel in the outer valve bore **52**, fuel is unable to flow past the insert seating **60** to the outlet **102**.

A method by which the inner and outer valves members **50**, **10** according to the first embodiment may be assembled within the nozzle body **6** will now be described, with general reference to the aforementioned FIGS. **1** to **7** and the reference numerals indicated therein.

Initially, the ring **70** is caused to receive the stem region **50***b* of the inner valve needle **50** so that the lower face **70***b* of the ring **70** abuts the internal seating **56** defined by the part-spherical head **50***a*. With the ring **70** in position, the stem region **50***b* is received in the sleeve **72** such that the ring **70** is retained on the inner valve needle **50**.

In order to set the predetermined distance ‘L’, a spacer tool, such as a shim of thickness ‘L’ (not shown), is positioned against the upper end face **70***a* of the ring **70**, whereby the sleeve **72** is pushed so as to engage the shim. When the shim is removed, the necessary separation of distance ‘L’ is established between the upper end face **70***a* of the ring **70** and the lower end face **72***a* of the sleeve **72**.

Following assembly of the inner valve needle **50**, the ring **70** and the sleeve **72**, the combined inner valve and ring/sleeve assembly is pushed into the bore **52** of the outer valve needle **10**. The inner and outer valves needles **50**, **10** are then together inserted into the nozzle body bore **8** such that the outer valve needle **10** engages with its internal and external seatings **56**, **32** and the inner valve needle **50** engages the inner valve seating **60**. Following assembly of the nozzle **4**, a seat bedding operation is performed in order to establish effective seals at the seatings of the inner and outer valve needles **50**, **10**, respectively. The seat bedding operation comprises applying a constant predetermined axial force to the outer valve needle **10**, which causes it to “bed in” over the external seating **32**. As an alternative to applying a predetermined constant axial force to the outer valve needle **10**, the bedding in operation could also be dynamic.

Regarding the manufacture of the embodiment in FIGS. **8** and **9**, to ensure that the outer valve needle **10** contacts with both internal and external seatings **56**, **32** simultaneously to provide an effective seal for the outlets **100**, the ring **110** is pushed into its final position by assembling all the components within the nozzle body **6** and applying a load to the outer valve needle **10** until a seal is formed such that fluid ceases to issue from the outlets **100**. Alternatively, the outer valve needle **10** could be pushed into the bore until it makes contact with its seating with a predetermined force. It will be appreciated that the above method could also be employed during the manufacture of the first embodiment.

It will be understood by those who practice the invention and those skilled in the art, that various modifications and improvements may be made to the invention without departing from the scope of the invention, as defined by the claims. For example, in the first, second and third embodiments the inner valve needle **50** is forced into engagement with its seating **60** by the high pressure fuel in the outer valve bore **52** and the ring **70** in abutment with the part-spherical head **50***a*. However, it is possible that, in use, the lower end face **70***a* of the ring **70** may wear such that a clearance develops at the seating **60** even when the inner and outer valve needle **50**, **10** are seated, so compromising the seal established by the inner valve needle **50** on the nozzle body **6**. To address this, it may be desirable to provide a resilient member such as a helical spring (not shown) within the chamber **62** to provide a further biasing force to the inner valve needle **50**. Such a spring may abut against an upper end face of the sleeve **72** such that the biasing force is transmitted to the inner valve needle **50** via the frictional coupling between these parts. Alternatively the spring may abut a separate abutment member located within the chamber **62**.

Furthermore, although the ring **70** and the sleeve **72** are coupled to the outer valve needle **10** and inner valve needle **50**, respectively, through frictional contact, it will be appreciated that coupling may be achieved through alternative arrangement, for example by gluing or soldering.

In addition, although the vent **102** in the embodiment described with reference to FIGS. **8** and **9** is axially disposed, it should be appreciated that this need not be the case. For example, the vent **102** may be parallel with the outlets **100** or at an angle to the central axis of the nozzle body **6**.

It should be understood that although the injection nozzle of the present invention has been described as suitable for use within an injector having a piezoelectric actuator, it is entirely possible that the injector may include an alternative form of actuator for moving the valve(s). For example, instead of a piezoelectric actuator, the outer valve may be moved by means of an electromagnetic actuator.

Although the nozzle body **6** has been described as defining the external seating **32** and the insert seating **60** for the outer valve needle **10** and the inner valve needle **50**, respectively, the nozzle body **6** may be provided with a lining plate, sleeve or similar so as to define these surfaces. Similarly, the ring **70** could be provided with a covering plate over its lower end face **70***a* to define that surface of the outer valve needle **10** that engages with the internal seating **56**. Also, either the inner valve needle **50** or the insert **104** could be provided with covering plates or similar so as to define the internal seating **56**. In another modification, the outer valve bore **52** may be provided with a lining sleeve, or similar component, so as to define the internal bore surface.

In an alternative embodiment, the inner valve needle **50** may be constructed differently so that the ring **70** forms an integral part of the outer valve needle **10**.

The invention claimed is:

1. The injection nozzle being such that the outer valve member disengages with the external seating at the same time as it disengages with the internal seating, while the insert remains seated on the seating surface,

- a nozzle body defining a seating surface and having a first nozzle outlet;
- an outer valve member received within the nozzle body and being engageable with an external seating defined by the seating surface so as to control fuel injection through the first nozzle outlet, the outer valve member defining a blind axial bore having an internal bore surface, the outer valve member defining a passage allowing continuous fluid communication between the bore and the exterior of the outer valve member; and
- an insert received within the bore, the insert defining an annular gap with the internal bore surface, wherein the outer valve member is engageable with an internal seating defined by a surface of the insert to control fuel flow through the annular gap to the first nozzle outlet,
- the injection nozzle being such that the outer valve member is arranged to disengage with the external seating at the same time as it disengages with the internal seating such that the fuel which is to be ejected from the nozzle is always caused to flow simultaneously along: (a) a first path between the outer valve member and the external seating; and (b) a second path through the annular gap.

2. The injection nozzle according to claim **1**, wherein the insert includes a part-spherical head which spans the internal diameter of the bore to define the annular gap.

3. The injection nozzle according to claim **2**, wherein the internal seating is defined by a surface of the part-spherical head.

4. The injection nozzle according to claim **3**, wherein the part-spherical head is engaged with an insert seating defined by the seating surface during at least a period of nozzle operation.

5. The injection nozzle according to claim **4**, further comprising a second nozzle outlet provided in the nozzle body, wherein the insert is an inner valve member which is slidable within the bore and engageable with the insert seating so as to control fuel injection through the second outlet.

6. The injection nozzle according to claim **5**, wherein the outer valve member includes an annular member which is received within the bore so as to be engageable with the internal seating.

7. The injection nozzle according to claim **6**, further comprising a sleeve member coupled to the inner valve member, wherein the annular member is brought into engagement with the sleeve member when the outer valve member is moved axially through a distance that is greater than a predetermined distance so as to impart axial movement to the inner valve member also.

8. The injection nozzle (**4**) according to claim **7**, wherein the annular member and the sleeve member have opposed end faces which are spaced apart by the predetermined distance when the outer valve member and the inner valve member are seated against their respective seatings.

9. The injection nozzle according to claim **8**, wherein an end face of the annular member that engages the internal seating is substantially flat.

10. The injection nozzle according to claim **8**, wherein an end face of the annular member that engages the internal seating is frusto-conical.

11. The injection nozzle according to claim **5**, wherein the inner valve member includes a valve stem, and wherein the internal seating is defined by a shoulder defined between the part-spherical head and the valve stem.

12. The injection nozzle according to claim **4**, wherein the insert remains engaged with the insert seating during all stages of nozzle operation.

13. The injection nozzle according to claim **12**, wherein the outer valve member includes an annular member which is received within the bore so as to be engageable with the internal seating.

14. The injection nozzle according to claim **12**, wherein the nozzle body is provided with a vent passage through which fuel can escape in the event of fuel leakage past the insert seating.

15. The injection nozzle according to claim **4**, further comprising an arrangement for urging the insert against the insert seating.

16. The injection nozzle according to claim **15**, wherein the arrangement for urging the insert against the insert seating includes the passage formed in the outer valve member which enables fuel to enter the bore, thereby to apply a hydraulic closing force to the insert.

17. The injection nozzle according to claim **15**, wherein the arrangement for urging the insert against the insert seating includes a spring.

18. The injection nozzle according to claim **1**, wherein the first path is provided past the external seating to the first outlet, and the second path is further provided to the first outlet past the internal seating when the outer valve member is unseated.

19. The injection nozzle according to claim **1**, wherein the external seating and the internal seating are positioned along the axis of the nozzle body in approximate alignment at least when the outer valve member is seated.

20. An injector for use in an internal combustion engine, wherein the injector includes an injection nozzle as claimed in claim **1** and an actuator for operating the injection nozzle.

21. The injector according to claim **20**, wherein the actuator is a piezoelectric actuator.

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